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TECHNICAL NOTE

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EFFECTS OF WATER-LANDING IMPACT ON AN ORBITAL CAPSULE FROM THE STANDPOINT OF OCCUPANT PROTECTION

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SUMMARY

The terminal phase of the flight of one type manned orbital capsule consists of a parachute descent through the lower atmosphere with a landing on water. One proposed configuration is a conical-shaped capsule with a segment of a sphere as the bottom. The spherical surface would be used as the landing surface as well as the reentry surface. A form-fitted heat shield would be attached to the bottom to provide protection during reentry and may be jettisoned before landing, if so desired. The water-landing characteristics of this type capsule have been investigated and it was found that an acceleration onset rate of approximately 25,000g/sec with an acceleration varying between 20g and 60g, depending upon the impact conditions, should be expected for an impact velocity of 30 ft/sec. This velocity is a reasonable parachute descent speed. The full-size model used for these tests had a 7-foot-diameter base, a 10.5-foot-radius spherical segment bottom, and weighed 1,172 pounds. This weight is representative of the capsule with the form-fitted heat shield removed.

Literature on human tolerance to rapid acceleration indicates that an acceleration rate of 1,500g/sec to a 40g level is about the maximum a human can endure without injury. The duration of the 40g level should not be more than 0.1 second. For this acceleration, at an initial velocity of 30 ft/sec, the distance required to stop is 8.54 inches. Thus, if the capsule were provided with some means (internally or externally) to ease the occupant down 8.54 inches within the tolerable acceleration limits during impact, he could survive the landing. Internally, the cushioning could be achieved with a crushable structure or a mechanical spring system.

INTRODUCTION

One proposed configuration for a manned orbital capsule has a conical-shaped body with a segment of a sphere as the bottom which would serve as a landing surface. Attached to the bottom would be a form-fitted heat shield that could be jettisoned before landing, if so desired. After returning to the atmosphere from orbit, the capsule would descend through the lower stratosphere and the troposphere with a parachute and finally land on water. In order to determine the water-landing characteristics of such a capsule, a full-scale model was dropped from a free-fall height of approximately 14 feet into water. This height was chosen to give the capsule an impact velocity of 30 ft/sec, which represents a reasonable parachute descent velocity for this type of capsule. A detailed description of the tests is presented in reference 1. The model used in these tests represents the proposed orbital capsule only in size, weight, shape, and center-of-gravity location. The weight of the model is representative of a capsule with the heat shield intact during landing.

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The data in the present paper were obtained from a continuation of the tests of reference 1. The same apparatus and procedure were used; however, the model capsule was lightened to represent a capsule with the heat shield removed. The purpose of this paper is to use the data from the lightened capsule, along with information on human tolerance to rapid acceleration, as a basis for discussing the problem of protecting an occupant from the landing impact.

APPARATUS AND PROCEDURE

The apparatus for these tests consisted of an instrumented capsule and a crane. A photograph of the apparatus with the capsule in the dropping position is shown in figure 1. The weight of the capsule used to obtain the data for this paper was 1,172 pounds, which is 978 pounds lighter than the capsule reported on in reference 1. Pertinent dimensions of the capsule are shown in figure 2. For a detailed description of the apparatus and test procedure, see reference 1.

The instrumentation in the capsule consisted of five accelerometers arranged according to the schematic diagram in figure 3. The X-, Y-, and Z-axes of the capsule were set according to the diagram in figure 4. All accelerometers were located in the YZ-plane through the center of gravity. Three accelerometers were located at the center of gravity and measured acceleration along each of the three axes. Two accelerometers were located at the periphery and measured acceleration parallel to the X-axis. Accelerometer outputs were conducted by wire to remotely located recording equipment. A summary of the accelerometer characteristics is presented in table I. Note that two of the accelerometers which measured accelerations in the direction of the X-axis had a high-frequency response.

In addition to simulating the 30-ft/sec parachute descent speed, the capsule was dropped into smooth water with different attitudes to simulate swaying beneath the parachute, and a horizontal velocity was imposed to represent wind drift. The attitude did not exceed ±30° from being vertical at impact, and the horizontal velocity did not exceed 14 ft/sec.

RESULTS AND DISCUSSION

An example of the acceleration experienced during water impact is shown in figure 5. This record was obtained from a vertical drop with the capsule impacting as shown in figure 6. In order to determine the effect that a water landing would have on an occupant, all vibrations and accelerations were taken into consideration. Figure 5 reveals that there were two main vibrations (100 cps and 500 cps) superimposed on the actual acceleration time history of the capsule during water impact. Traces 3 and 4 are the only traces containing the 500-cps vibration inasmuch as accelerometers 3 and 4 were the only accelerometers with high enough frequency response to sense such a low-amplitude high-frequency vibration. The source of the 500-cps vibration is unknown, but it is not of great importance since a human could be protected from this with present-day conventional support systems. The 100-cps vibration had a higher amplitude (structural deflection approximately 1/4 inch); if a human were exposed directly to this combination of amplitude and frequency for extended exposures, he would find it painful to unbearable (ref. 2). But the duration of the 100-cps and the 500-cps vibration during water impact was very short and a human may not need special support to protect him from this vibration. The 100-cps vibration, presumably caused by the flexing of the bottom, is local in nature and will vary with the construction of the actual capsule. Localized vibrations will be present in any capsule and should be considered in providing protection for the occupant.

The acceleration time history of the capsule as a whole can be determined by fairing the accelerometer data as trace 3 in figure 5. In general, the peak accelerations for all types of drops with the lightened capsule were approximately 10g higher than those in reference 1. The highest acceleration reached was approximately 60g and was recorded in a drop where the capsule landed with a vertical attitude and a horizontal velocity component.

Figure 7 presents faired accelerometer traces for each type of drop. The 100-cps vibration was included to show its effect on the record. Zero time was arbitrarily chosen as approximately 0.05 second before water contact. Figure 7 also shows that the peak acceleration during impact was greatly reduced when the capsule was dropped with an attitude of approximately ±30° from the vertical.

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The effect of rapid acceleration on a human being has been investigated extensively in the past few years, and a good deal of information on this subject has been compiled in reference 3. Most of the information presented in reference 3 is in terms of an onset rate of acceleration and a maximum acceleration for various body orientations. Since an occupant is to be orientated so that the long axis of his spine is perpendicular to the X-axis of the capsule, the tolerance presented in this paper will be taken from data that reference 3 has termed "sternumward"; that is, forces applied to the back surfaces of the body to resist further motion are acting toward the sternum. Reference 3 indicates that a human can withstand, without injury, a rate of 1,500 g/sec with a maximum of 40g applied sternumward. However, he can not endure the 40g level for more than 0.1 second without injury. Although these limits of man's tolerance to abrupt acceleration may be conservative, they are used in this paper for lack of data for higher accelerations. Figure 5 shows that the onset rate of acceleration on the capsule during water impact was approximately 25,000g/sec with a peak of 60g. Thus, some cushioning device is needed that will change the high rate of acceleration during impact to the tolerable rate of 1,500g/sec. This so-called cushioning of the occupant can be accomplished with either internal or external devices; however, this paper will discuss only internal devices.

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One internal method of providing protection for the occupant would be to place a crushable material between the occupant and the bottom of the capsule. At impact, the occupant's kinetic energy would be used up in crushing the material with a tolerable acceleration rate. In order to determine how much material would be needed between the occupant and the bottom of the capsule, the distance required to stop from 30 ft/sec at the tolerable rate must be calculated. From physical laws, an object traveling with a 30-ft/sec velocity requires 8.54 inches to stop if it is accelerated at a rate of 1,500g/sec until it reaches 40g and then is finally stopped at the constant level of 40g.

Under these conditions a crushable structure would deflect elastically under an increasing load until a critical load is reached; then the substance would fail and continue to deflect with no further increase in load. In order to meet the requirements, the structure must remain in its elastic range for a deflection of 7.78 inches and then fail for the additional 0.76 inch. Thus, almost all the distance to stop is used up in the elastic range of the structure, a fact which would suggest that a true mechanical spring system might be more feasible. The main problem with a spring system would be controlling the rebound.

It should be pointed out here that the offset rate of acceleration from 40g has not been taken into consideration. No information could be obtained on human tolerance to offset rates of acceleration from various g-levels; however, reference 3 assumes a trapezoidal acceleration time history so that the offset rate would be the same as the onset rate.

This assumption would seem to complicate the calculated distance required to stop; however, the offset rate could be achieved by a small amount of rebound. Thus, no more than 8.54 inches would be required to stop and a definite offset rate could be achieved.

CONCLUDING REMARKS

A series of tests have been made with a conical-shaped body with a segment of a sphere as the base by dropping it into water to determine the water-impact acceleration. This configuration is one proposal for a manned orbital capsule which, after returning from orbit, would descend through the lower atmosphere under a parachute and land in water. The spherical surface serves as the water-landing surface as well as a heat shield during reentry. The heat shield is form fitted and may be jettisoned before landing, if so desired. Data obtained from a model with a 7-foot-diameter base and a 10.5-foot-radius spherical segment base revealed that the maximum acceleration experienced was 60g with a 25,000-g/sec rate of onset of acceleration. These values were obtained from a drop test which simulated a horizontal velocity of 14 ft/sec at impact and a vertical velocity of 30 ft/sec. The weight of the model used for this paper (1,172 pounds) is representative of a capsule with the heat shield removed.

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Literature on human tolerance to acceleration during time intervals somewhat longer than those of water impact indicated that an acceleration rate of 1,500g/sec to a level of 40g is about the maximum for survival without injury. The duration at 40g should not exceed 0.1 second. For the velocity expected with a parachute (30 ft/sec), the distance required to stop within the tolerable limits is 8.54 inches. In order to protect the occupant, the capsule must be provided with some means - internally or externally - to cushion the occupant during landing. For example, a crushable material could be placed between the occupant and the bottom of the capsule or a mechanical spring system could be used.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., May 25, 1959.

REFERENCES

1. McGehee, John R., Hathaway, Melvin E., and Vaughan, Victor L., Jr.: Water-Landing Characteristics of a Reentry Capsule. NASA MEMO 5-23-59L, 1959.

2. McFarland, Ross A.: Human Factors in Air Transportation. McGraw-Hill Book Co., Inc., 1953, p. 703.

3. Eiband, A. Martin: Human Tolerance to Rapidly Applied Accelerations: A Summary of the Literature. NASA MEMO 5-19-59E, 1959.

TABLE I

ACCELEROMETER CHARACTERISTICS

Accelerometer (a)	Location	Positioned to measure -	Sensitivity, g units	Natural frequency, f_N, cps	Characteristics of frequency-response curve
1	At c.g.	Along Y-axis	20	161	Flat within ±3 percent to $0.5f_N$
2	At c.g.	Along Z-axis	50	156	Flat within ±5 percent to $0.5f_N$
3	At c.g.	Along X-axis	100	640	Flat within ±5 percent to $0.8f_N$
4	At periphery	Parallel to X-axis	100	655	Flat within ±3 percent to $0.8f_N$
5	At periphery	Parallel to X-axis	50	372	Flat within ±5 percent to $0.7f_N$

[a]See figure 3 for schematic diagram of accelerometer arrangement in capsule.

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Figure 1.- View of apparatus with capsule in dropping position preceding a drop simulating a horizontal velocity component.

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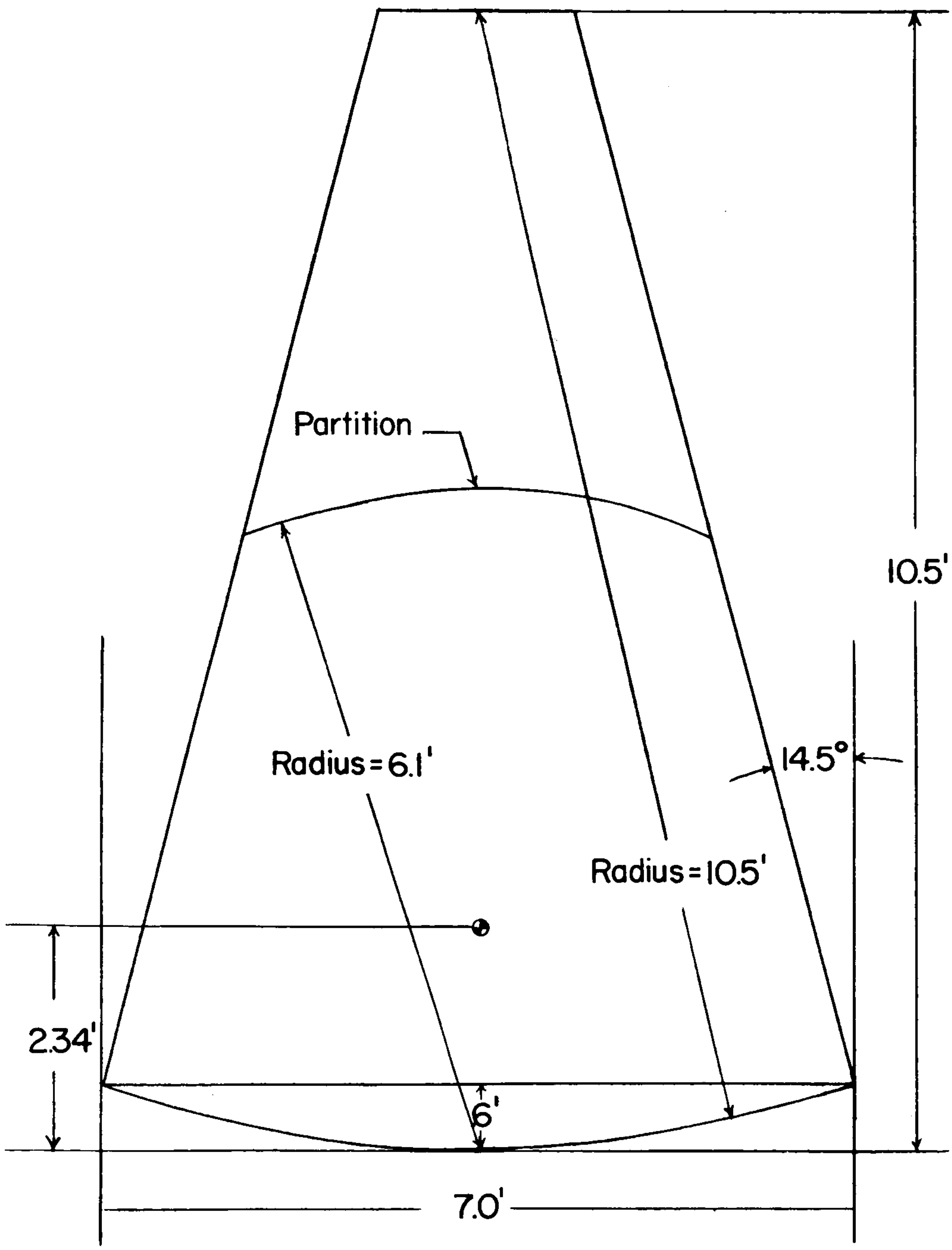


Figure 2.- Dimensions and shape of the test capsule.

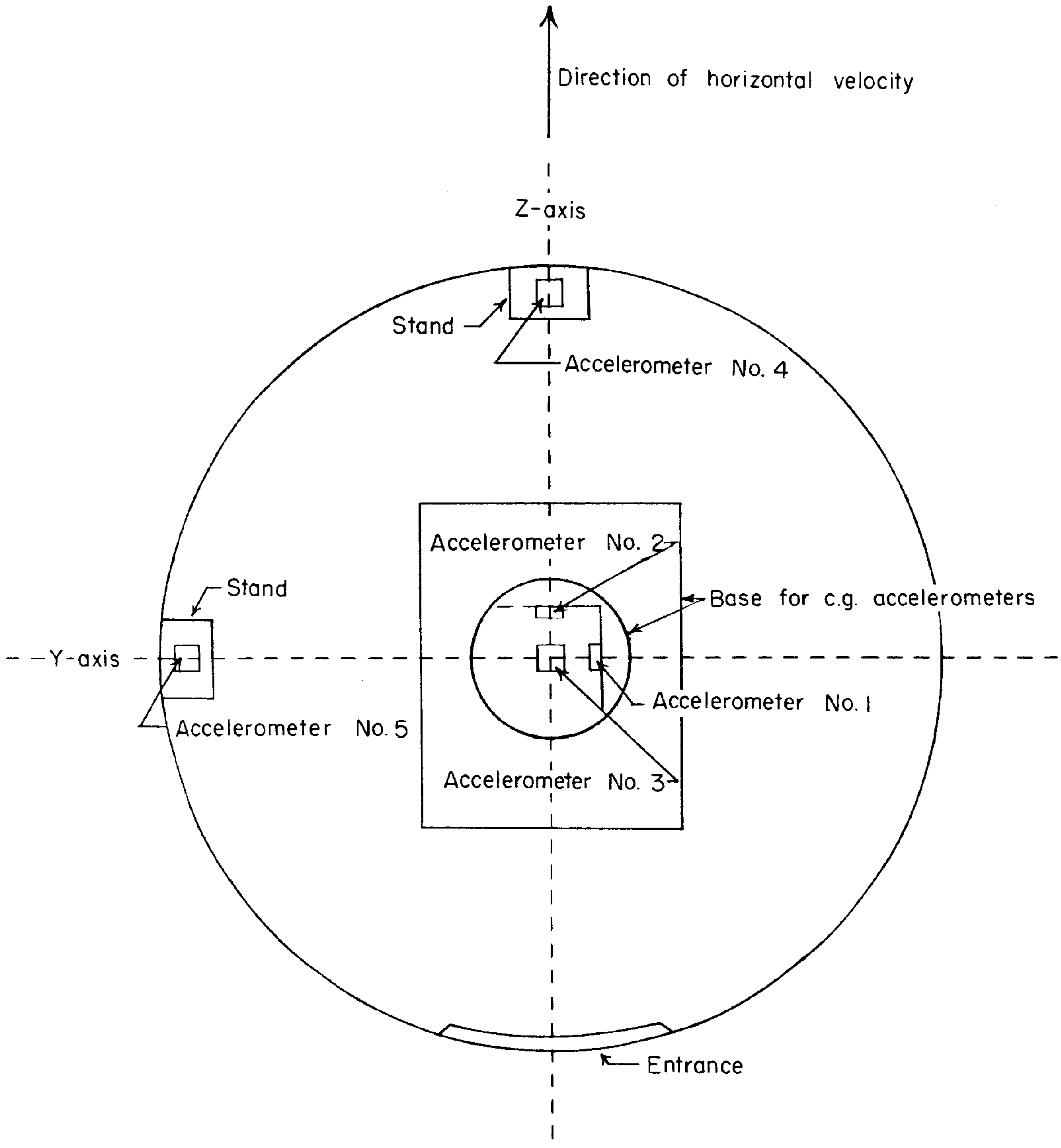


Figure 3.- Top view of the arrangement of accelerometers within the capsule.

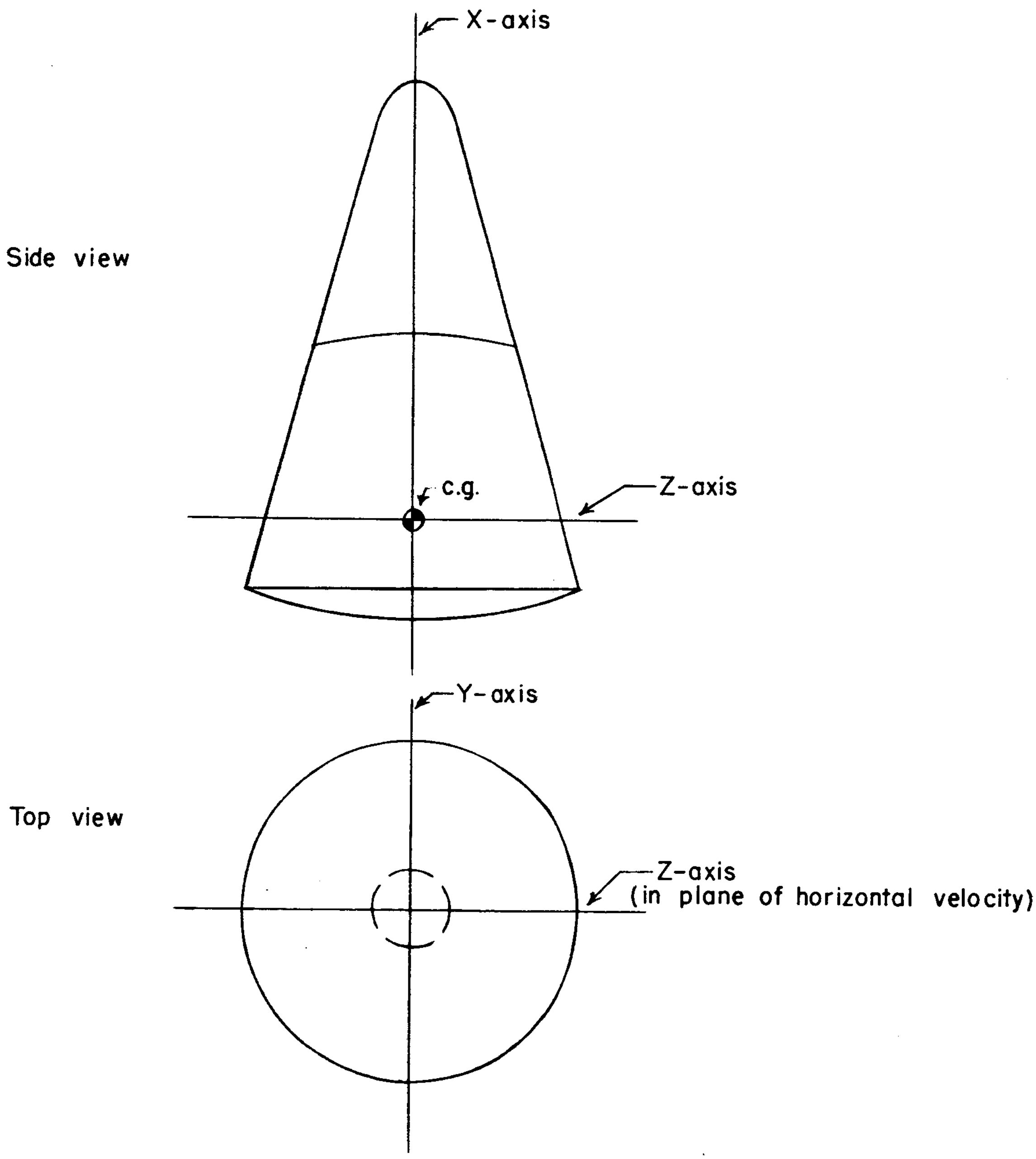


Figure 4.- Diagram showing axis system of model capsule.

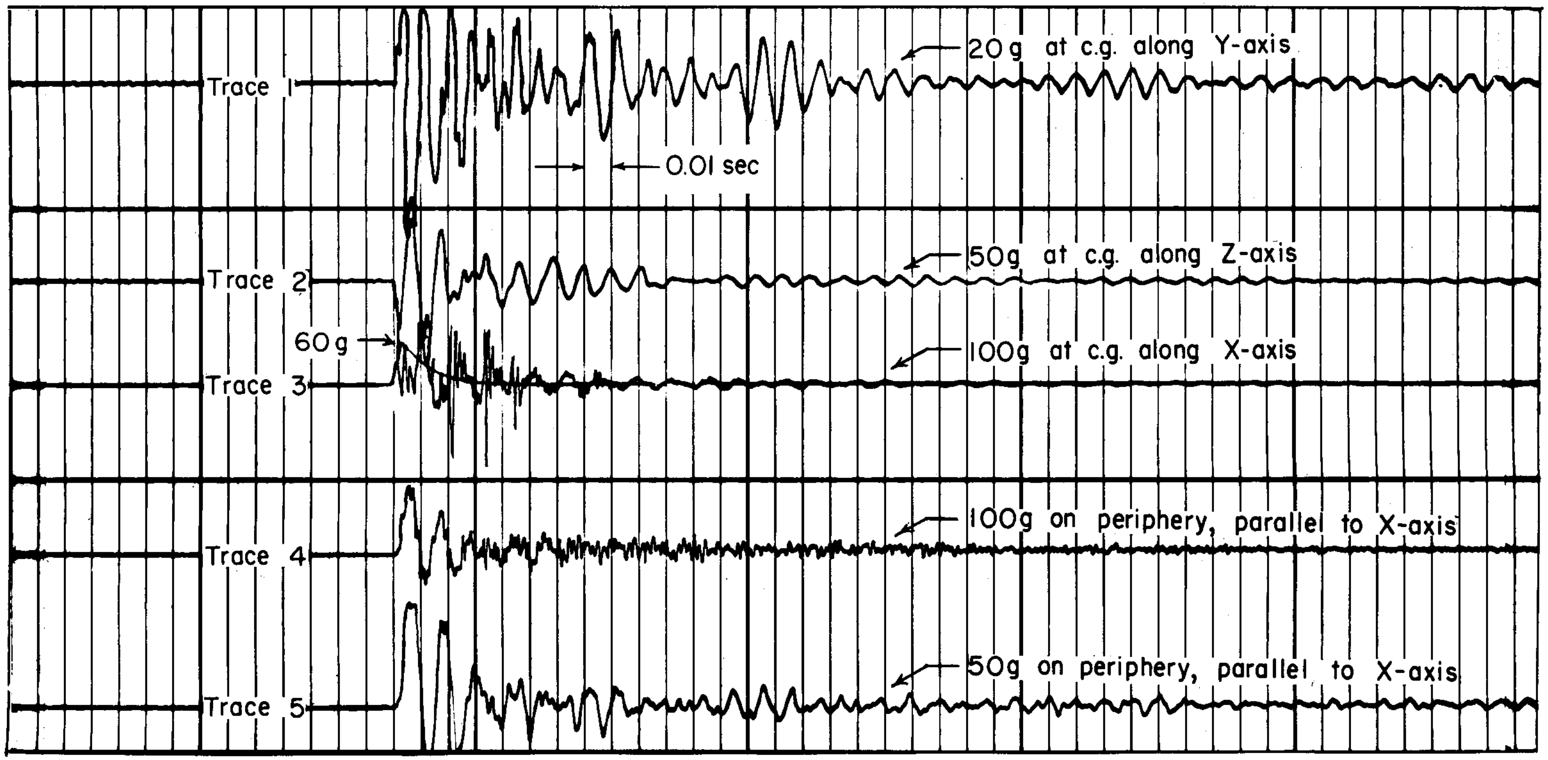


Figure 5.- Example accelerometer record taken from vertical drop with the capsule impacting as shown in figure 6.

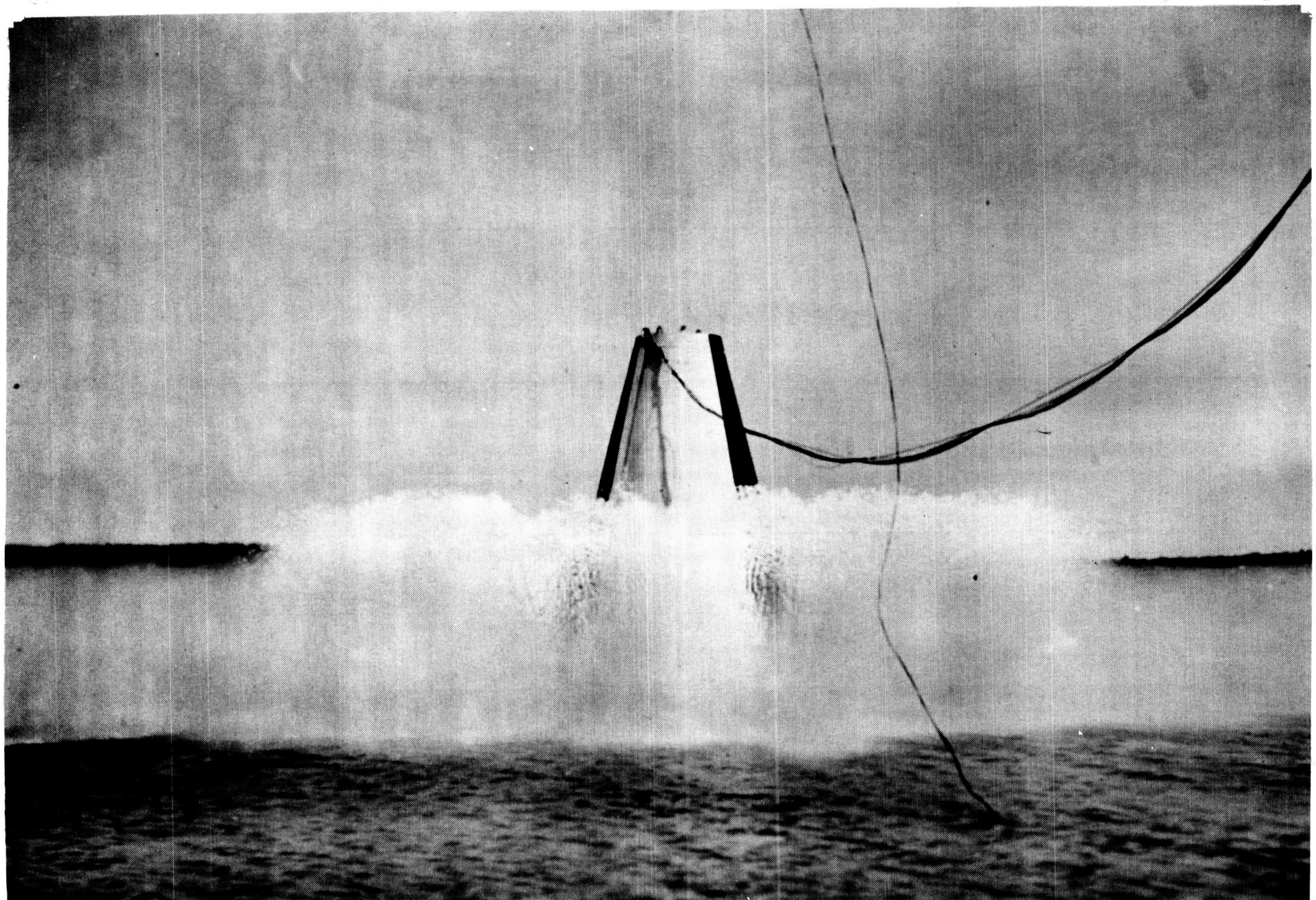
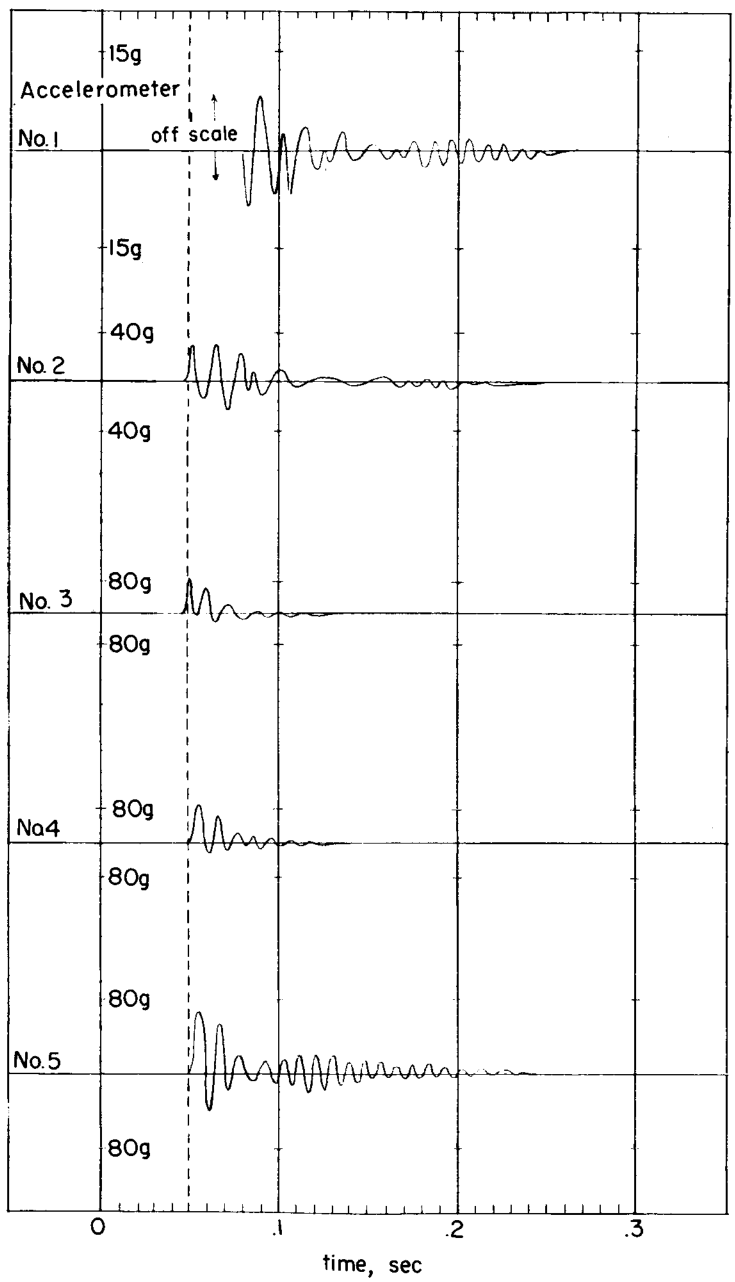


Figure 6.- A vertical drop. L-58-3339



(a) Vertical impact with horizontal velocity simulating wind drift.

Figure 7.- Faired accelerometer traces for different types of drops.

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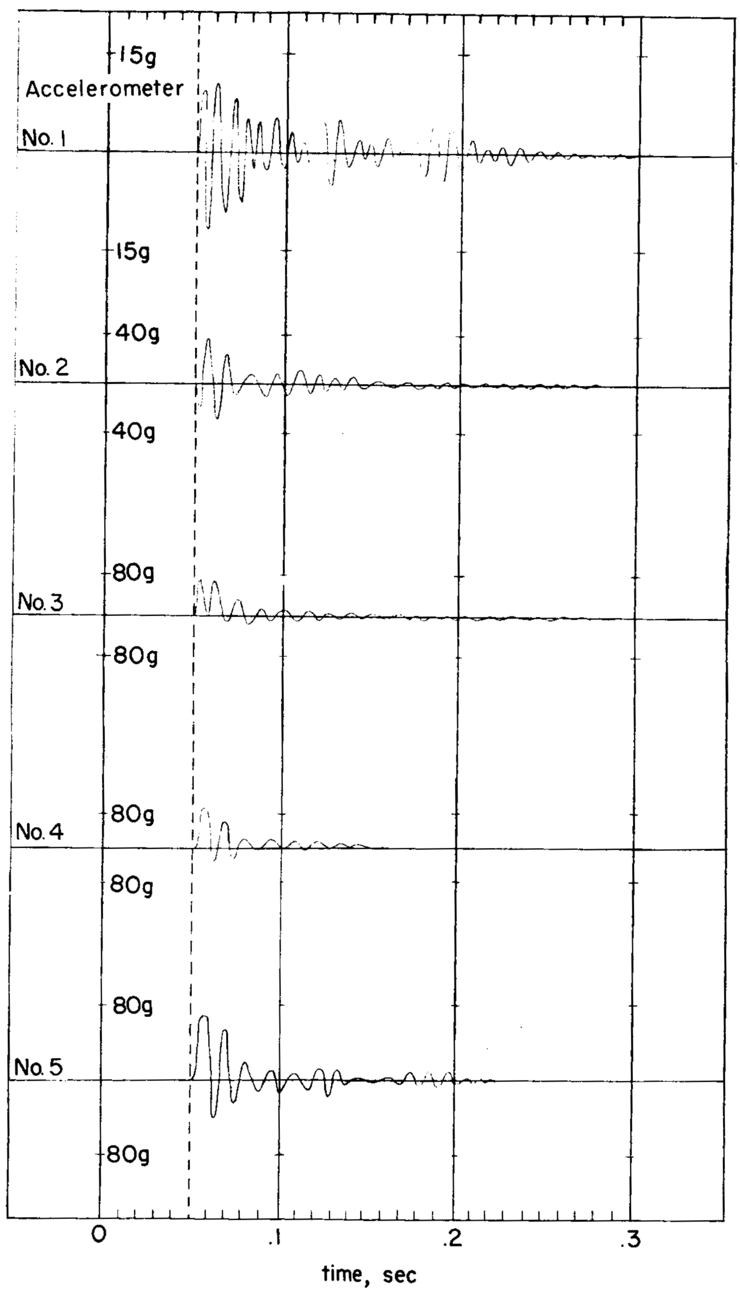
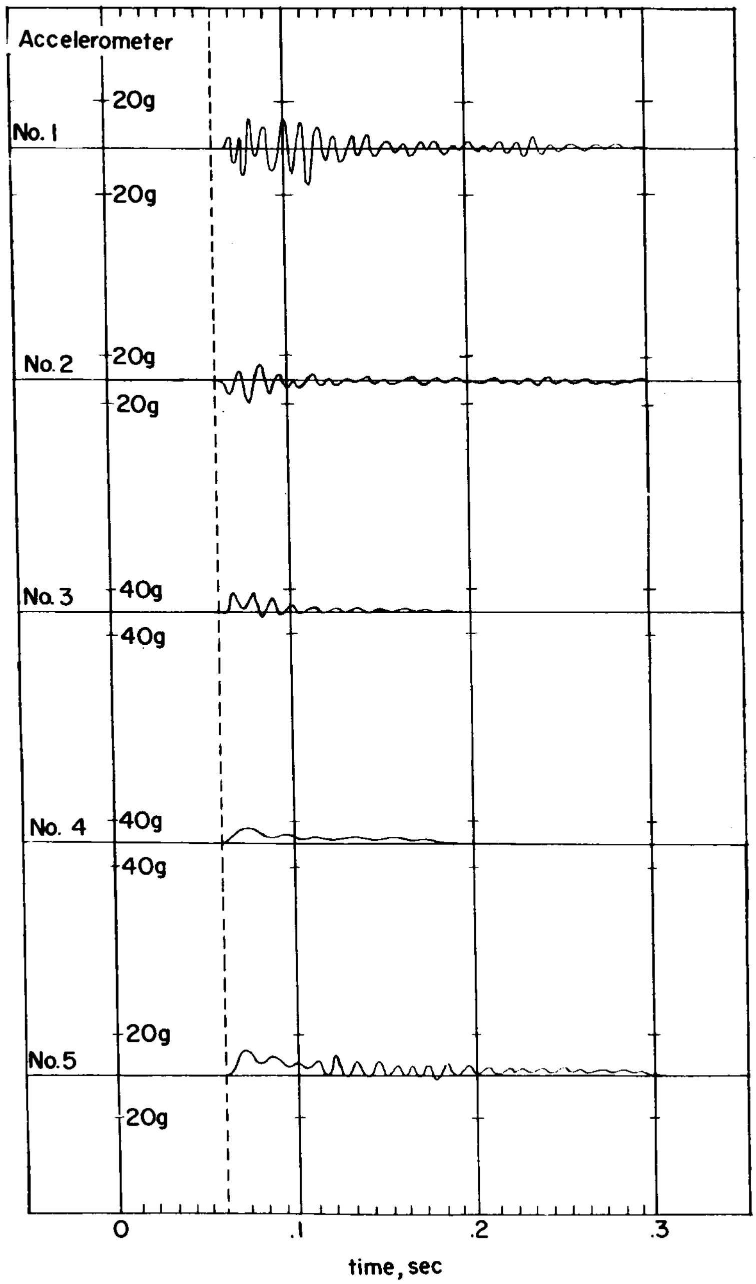


(b) Vertical impact with no horizontal velocity.

Figure 7.- Continued.



(c) Impact with an attitude of 30° from vertical with horizontal velocity. These conditions represent wind drift and oscillation of the capsule beneath the parachute. (Leading edge of bottom entered water first.)

Figure 7.- Continued.

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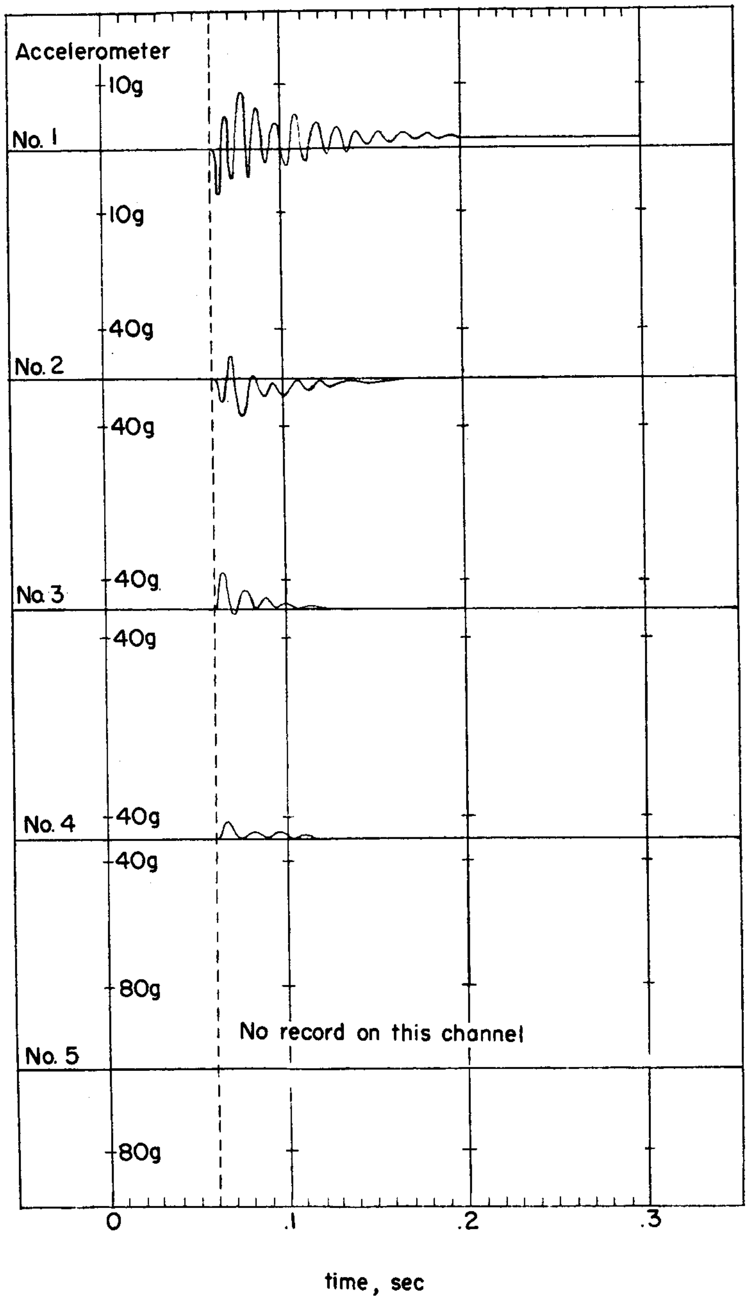
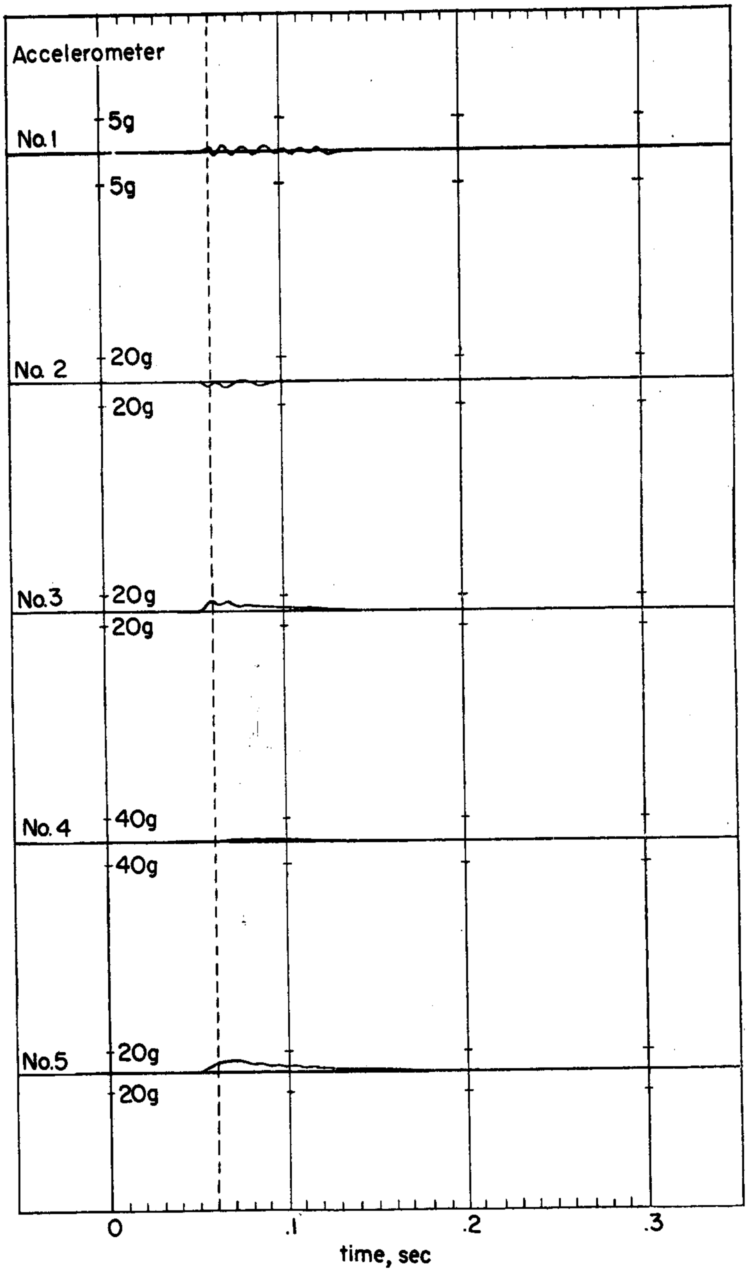


(d) Impact with an attitude of 30° from vertical with horizontal velocity. These conditions represent wind drift and oscillation of the capsule beneath the parachute. (Trailing edge of bottom entered water first.)

Figure 7.- Continued.



(e) Impact with an attitude of 30° from vertical with no horizontal velocity. This condition simulates oscillation of the capsule with no wind drift.

Figure 7.- Concluded.